

National Aeronautics and Space Administration

## FINAL TECHNICAL REPORT FOR NAG 8-497

## Submitted to:

National Aeronautics and Space Administration  
Attention of: Donna Havrisik  
NASA Technical Officer  
Code EM-25  
George C. Marshall Space Flight Center  
Marshall Space Flight Center, AL 35812

## Submitted by:

The Trustees of Columbia University  
in the City of New York  
Box 20, Low Memorial Library  
New York, New York 10027

## Prepared by:

Columbia Astrophysics Laboratory  
Departments of Astronomy and Physics  
Columbia University  
538 West 120<sup>th</sup> Street  
New York, New York 10027

## Principal Investigator:

David J. Helfand  
Professor of Physics

## Title of Research:

"Analysis and Interpretation of Data  
from the EINSTEIN Satellite"

## Termination Date:

30 September 1990

(NASA-CR-193756) ANALYSIS AND  
INTERPRETATION OF DATA FROM THE  
EINSTEIN SATELLITE Final Technical  
Report, period ending 30 Sep. 1990  
(Columbia Univ.) 13 p

N93-72700

Unclassified

29/89 0181237

## I. INTRODUCTION

The grant entitled *Analysis and Interpretation of Data from the Einstein Satellite* has formed the principal source of support for the scientific participation of the Columbia University Consortium partner in the HEAO-2 program over the past six years. The Consortium science program has now formally ended. We summarize here the technical and scientific accomplishments of the Columbia program throughout the period of this grant: 1 October 1984 through 30 September 1990.

## II. PERSONNEL

A total of eleven Columbia faculty members, eighteen Columbia graduate students, nearly a dozen undergraduate students, and seventeen technical staff (principally programmers, a system manager, and office personnel) have worked on research projects supported by the grant over this period. The scientific staff and students along with the approximate duration of their affiliations with the program are summarized in Table 1. Seven of the graduate students received Ph.D.s for work largely concerned with the HEAO-2 data during these six years, while several others gained valuable research experience during a summer or two and are now pursuing dissertations in other areas. Dissertation titles and degree award dates are given in Table 2. Of the undergraduates involved in the program, at least five are now in graduate school in Astronomy or Physics and several more are planning to pursue careers in this area upon graduation.

### III. PUBLICATIONS

The research carried out under this grant has spanned many areas of modern astrophysics, and a detailed summary of the work accomplished is best obtained from the more than 80 scientific publications which have appeared in the literature. In Table 3, we summarize the publication statistics including refereed papers and contributions to conference proceedings by faculty, post-docs, and students supported under this program. It is noteworthy that, even twelve years after the launch of HEAO-2 and nearly a decade after its demise, developments in the field along with our increasingly sophisticated exploitation of the database has yielded ten refereed publications from Columbia's participation in the mission in the current Calendar year. The grand total for Columbia contributions under the HEAO-2 Consortium program now stands at 132 papers.

A complete bibliography of the papers produced with the support of this grant appears as Appendix A. The bibliography is in reverse chronological order and includes all papers published or submitted for publication before the termination date of this grant on 30 September 1990. Articles in refereed journals and unrefereed conference proceedings are listed separately. Abstracts of talks presented are omitted from the list.

**TABLE 1: PERSONNEL**

Name	Duration
<b>Faculty</b>	
G.A. Chanan .....	84
J. Halpern .....	84 - 90
D.J. Helfand .....	84 - 90
S. Kahn .....	84
W.H.-M Ku .....	84 - 85
J. Patterson .....	86
R. Novick .....	84 - 85
M. Ruderman .....	86
J. Shaham .....	86
A. Szentgyorgyi .....	89
D. Tytler .....	88
<b>Graduate Research Assistants</b>	
J.-P Caillault .....	84 - 85
S. Crane .....	86
K. Chen .....	88 - 89
M. Eracleous .....	89 - 90
E. Gotthelf .....	89 - 90
T. Hamilton .....	85 - 90
J. Hughes .....	84
K. McLin .....	86
J. Mechalakos .....	88
R. Pisarski .....	84
R. Ray .....	89
E. Rubenstein .....	90
J. Terman .....	89
S. Vrtilek .....	84 - 85
Q. Wang .....	87 - 90
X. Wu .....	87 - 90
K. Xu .....	90
S. Zoonematkermani .....	87
<b>Undergraduate Students</b>	
E. Artanian .....	89 - 89
S. Bloom .....	87
J. Broekman .....	89 - 90
V. Chen .....	88 - 90
R. King .....	87
R. Monier .....	86 - 88
E. Haxthausen .....	86 - 88
B. Hufnagel .....	87 - 89
H. Richman .....	89 - 90
K. Sanbonmatsu .....	88 - 90
S. Thaler .....	87

TABLE 2: SUMMARY OF Ph.D. RECIPIENTS

Name	Title of Dissertation	Year
Ryszard L. Pisarski	"A Soft X-ray Survey of Galactic Supernova Remnants with the <i>Einstein</i> Observatory"	1984
John P. Hughes	"A Self-Consistent Model for X-ray Emission from Supernova Remnants"	1984
Saeqa D. Vrtilek	"Bright Galactic X-ray Binary Sources: Temporal and Spectral Studies"	1985
Jean-Pierre Caillault	"Observations of Coronal X-ray Sources and an Analysis of the Stellar Contribution to the Soft X-ray Background"	1985
Thomas Hamilton	"The Origin of the Diffuse X-ray Background"	1988
Xiaoyi Wu	"Observations of the Cosmic X-ray Background at 4 keV"	1990
Qingde Wang	"The Hot ISM in the Large Magellanic Cloud"	1990

TABLE 3: PUBLICATIONS SUMMARY

Year	Refereed Publications			Conference Proceedings		Total Publications
	CAL 1 <sup>st</sup> Author	CAL Coauthor(s)	CAL Total	CAL 1 <sup>st</sup> Author	CAL	
Prior to 84:	34	16	50	11		61
84	11	7	18	7		25
85	10	6	16	1		17
86	6	0	6	0		6
87	6	4	10	2		12
88	1	2	3	0		3
89	2	0	2	1		3
90	1	0	1	4		5
91 (in press)	10	0	10	0		10
Total 84 - 90	47	19	66	15		
Total CAL HEAO Program	81	35	106	26		132

## APPENDIX A

### Refereed Publications 1984 – 1990

- Eracleous, M., Halpern, J., and Patterson, J. 1991, "X-ray Spectra of Cataclysmic Variables Observed from the *Einstein* Observatory, *Ap.J.*, submitted\*.
- Eracleous, M., Patterson, J. and Halpern, J.P. 1991, *Ap.J.*, in press\*.
- Halpern, J.P., Chen, V.S., Madejski, G., and Chanan, G.A., 1991, "The Redshift of the X-ray Selected BL Lacertae Object H0414+009," *Astron. J.*, in press\*.
- Hamilton, T.T., Helfand, D.J., and Wu, X 1991, "Faint X-ray Source Counts and the Origin of the X-ray Background," *Ap.J.*, in press\*.
- Kolman, M., Halpern, J.P., Schrader, C.R., and Filippenko 1991, A.V., *Ap.J.*, **373**, 000\*.
- Wang, Q., and Helfand, D.J. 1991, "LMC 2 as the Blowout of a Hot Superbubble," *Ap.J.*, in press\*.
- Wang, Q., and Helfand, D.J. 1991, "An X-ray Image of the Violent Interstellar Medium in 30 Doradus," *Ap.J.*, in press\*.
- Wang, Q., and Helfand, D.J. 1991, "The Detection of X-ray Emission from the OB Associations of the Large Magellanic Cloud," *Ap.J.*, in press\*.
- Wang, Q., Hamilton, T., Helfand, D.J., and Wu, X. 1991, "The Detection of X-rays from the Hot Interstellar Medium of the Large Magellanic Cloud," *Ap.J.* in press\*.
- Wu, X., Hamilton, T.T., Helfand, D.J., and Wang, Q. 1991, "The Intensity and Spectrum of the Diffuse X-ray Background," *Ap.J.*, in press\*.
- Patterson, J., and Halpern, J.P. 1990, "On the Nature of the X-ray Pulsar Near L1457," *Ap.J.*, **361**, 173.
- Helfand, D.J., and Chanan, G.A 1989, "A Search for X-ray Counterparts to Small-Diameter Galactic Radio Sources," *A.J.*, **98**, 1652.
- Wang, Q., Hamilton, T., and Helfand, D.J. 1989, "The Hot Interstellar Medium Toward SN1987A," *Nature*, **341**, 309.

---

\* Submitted before termination of Grant on September 1990; to appear in, or has appeared in 1991.

- Becker, R.H., and Helfand, D.J. 1988, "The Dual Nature of the Supernova Remnant G351.2 + 0.1," *A.J.*, **95**, 883.
- Halpern, J.P., and Tytler, D. 1988, "The Geminga X-ray Counterpart and a Blue Optical Identification," *Ap.J.*, **330**, 201.
- Lee, M.G., Balick, B., Halpern, J.P., and Heckman, T.M. 1988 "A Soft X-ray Flare in the Seyfert 1 Galaxy Markarian 335," *Ap.J.*, **331**, 154.
- Becker, R.H., and Helfand, D.J. 1987, "High Resolution X-ray and Radio Images of the Galactic SNR G39.2 - 0.3," *A.J.*, **94**, 1629.
- Becker, R.H., and Helfand, D.J. 1987, "High Resolution Radio Observation of the SNR G24.7 + 0.6: Discovery of an Embedded Ultra-Compact HII Region," *Ap. J.*, **316**, 660.
- Beuerman, K., Stella, L., and Patterson, J. 1987, "*Einstein* Observations of EF Eridani (2A 0311-227), The Textbook Example of Am Herculis-Type Systems," *Ap. J.*, **316**, 360.
- Halpern, J.P., and Patterson, J. 1987, "A Hard X-ray Source in the Nearest Molecular Cloud," *Ap. J. (Letters)*, **312**, L31.
- Halpern, J.P., and Oke, J.B., 1987, "Narrow-Line Seyfert Galaxies with Permitted Fe II Emission: Markarian 507, 5C 3.100, and I Swicky 1," *Ap.J.*, **312**, 91.
- Hamilton, T. and Helfand, D.J. 1987, "The Origin of the Diffuse X-ray Background," *Ap. J.*, **318**, 93.
- Helfand, D.J. and Becker, R. 1987, "G0.9+0.1 and the Emerging Class of Composite Supernova Remnants," *Ap. J.*, **314**, 203.
- Monier, R., and Halpern, J.P. 1987, "The X-ray Spectrum of NGC 1068," *Ap.J. (Letters)*, **315**, L17.
- Singh, K.P., Westergaard, N.J., Schnopper, H.W., and Helfand, D.J. 1987, "X-ray Observations of SNR N103B in the Large Magellanic Cloud," *Ap. J.*, **322**, 80.
- Vrtilek, S.D., Chanan, G.A., Helfand, D.J., Kahn, S.M., Grindlay, J.E., and Seward, F.D. 1987, "High Resolution X-ray Spectroscopy of Three Galactic Bulge Sources," *Ap. J.*, **308**, 644.
- Caillault, J.-P. Helfand, D.J., Nousek, J.A., and Takalo, L.O. 1986, "X-ray Selected M-Dwarfs and the Diffuse X-ray Background," *Ap. J.*, **304**, 318.



- Halpern, J.P., and Oke, J.B. 1986, "Detection of [Ni II]  $\lambda$ 7378 in Six Seyfert Galaxies," *Ap. J.*, **301**, 753.
- Halpern, J.P., Impey, C.D., Tapia, S., and Wilson, A.S. 1986, "1E 1415.6+2557: An X-ray-Selected BL Lac Object in a Luminous Galaxy," *Ap. J.*, **302**, 711.
- Halpern, J.P., and Filippenko, A.V. 1986, "NGC 6212: An X-ray Selected Active Elliptical Galaxy," *A. J.*, **91**, 1019.
- Kahn, S.M., and Caillault, J.-P. 1986, "Einstein Observations of the Soft X-ray Background Close to the Galactic Plane," *Ap. J.*, **305**, 526.
- Vrtilek, S.D., Kahn, S.M., Grindlay, J.E., Helfand, D.J., and Seward, F.D. 1986, "Spectral Variability of Cygnus X-2: Structure in the Circumsource Material," *Ap. J.*, **307**, 698.
- Alpar, M.A., Anderson, P.W., Pines, D., and Shaham, J. 1985, "Vortex Creep and the Internal Temperature of Neutron Stars, II. Vela Pulsar," *Ap. J.*, **278**, 791.
- Alpar, M.A., and Shaham, J. 1985, "GX 5-1: A Millisecond Pulsar?" *Nature*, **316**, 239.
- Caillault, J.-P., Chanan, G.A., Helfand, D.J., Patterson, J., Nousek, J.A., Takalo, L., Bothun, G., and Becker, R. 1985, "The Peculiar X-ray Radio Source AS431," *Nature*, **313**, 376.
- Caillault, J.-P., and Helfand, D.J. 1985, "The *Einstein* Soft X-ray Survey of the Pleiades," *Ap. J.*, **289**, 279.
- Kriss, G.A., Becker, R.H., Helfand, D.J., and Canizares C. 1985, "G27.4 - 0.0: A Galactic SNR with a Compact Central Source," *Ap. J.*, **288**, 703.
- Lamb, F.K., Shibazaki, N., Alpar, M.A., and Shaham, J. 1985 "Quasiperiodic Oscillations in Bright Galactic Bulge X-ray Sources," *Nature*, **317**, 681.
- Halpern, J. 1985, "X-ray Spectrum and Variability of 3C 120," *Ap. J.*, **290**, 130.
- Halpern, J.P., Grindlay, J.E., and Tytler, D. 1985, "Observations of the Geminga Optical Candidate," *Ap. J.*, **296**, 190.
- Hughes, J.P., and Helfand, D.J. 1985, "Self Consistent Models for the X-ray Emission from Supernova Remnants: An Application to Kepler's Remnant," *Ap. J.*, **291**, 544.

- Margon, B., Downes, R., and Chanan, G. 1985, "An Atlas of X-ray Selected Quasi-Stellar Objects," *Ap. J. (Supplements)*, **59**, 23.
- Matthewson, D.S., Ford, V.L., Tuohy, I.R., Mills, B.Y., Turtle, A.J., and Helfand, D.J. 1985, "Supernova Remnants in the Magellanic Clouds: III," *Ap. J. Suppl.*, **58**, 197.
- Patterson, J., and Raymond, J.C. 1985, "X-ray Emission from Cataclysmic Variables with Accretion Disks. I. Hard X-rays," *Ap. J.*, **292**, 535.
- Patterson, J., and Raymond, J.C. 1985, "X-ray Emission from Cataclysmic Variables with Accretion Disks. II. EUV/Soft X-ray Radiation," *Ap. J.*, **292**, 550.
- Ruderman, M.A., and Shaham, J.S. 1985, "Disruption of Light He Companions in Accreting Neutron Star Binaries," *Ap. J.*, **289**, 244.
- Watson, M.G., Willingdale, R., King, A.R., Grindlay, J.E., and Halpern, J. 1985, "The Big Dipper: 4U1624-49," *Space Sci. Rev.*, **40**, 195.
- Vrtilek, S., and Halpern, J.P. 1985, "Temporal and Spectral Study of a Newly-Discovered Spiking Phenomenon in the Pre-Eclipse and Anomalous Dip States of Her X-1: Yet Another Periodicity?" *Ap. J.*, **296**, 606.
- Bregman *et al.* 1984, "Multifrequency Observations of the BL Lacertae Object 0735+178," *Ap. J.*, **276**, 454.
- Chanan, G.A., Helfand, D.J., and Reynolds, S.P. 1984, "An Optical Synchrotron Nebula Around the X-ray Pulsar 0540-693 in the Large Magellanic Cloud," *Ap. J. (Letters)*, **287**, L23.
- Chanan, G.A., and Abromopoulos, F. 1984, "The Radial X-ray Brightness Profile of the Coma Cluster," *Ap. J.*, **287**.
- Cowley, A.D., Crampton, D., Hutchings, J.B., Thorstensen, J.R., Charles, P.A., Helfand, D.J., and Hamilton, T.T. 1984, "Stellar Counterparts of the Large Magellanic Cloud X-ray Sources," *Ap. J.*, **286**, 196.
- Helfand, D.J. 1984, "Endpoints of Stellar Evolution: X-ray Surveys of the Local Group," *P.A.S.P.*, **96**, 913.
- Helfand, D.J., Chance, D., Becker, R.H., and White, R.L. 1984, "VLA Maps of Compact Radio Sources in the Galactic Plane: A Search for Crab-Like Supernova Remnants," *A.J.*, **89**, 819-823.

- Helfand, D.J., and Becker, R.H. 1984, "The Observation of Stellar Remnants from Recent Supernovae," *Nature*, **307**, 215-221.
- Hughes, J., Helfand, D.J., and Kahn, S.M. 1984, "On the Number-Diameter Relation of Supernova Remnants in the LMC," *Ap. J. (Letters)*, **281**, 25-28.
- Jura, M., and Helfand D.J. 1984, "X-rays from Mira: Accretion from Red Giant Winds," *Ap. J.*, **287**, 785.
- Kahn, S.M., Seward, F.D., and Chlebowsky, T. 1984, "High Resolution Soft X-ray Spectra of Scorpius X-1: The Structure of Circumsource Accreting Material," *Ap. J.*, **283**, 286.
- Kahn, S.M., and Grindlay, J.E. 1984, "X-ray Bursts from Cygnus X-2 and GX17+2," *Ap. J. (Letters)*, **281**, 826.
- Kahn, S., Wesemael, F., Liebert, J., Raymond, J.C., Steiner, J.E., and Shipman, H.S. 1984, "Soft X-Radiation from Hot DA White Dwarfs: Constraints on the Surface Abundances of Helium," *Ap. J.*, **278**, 255.
- Ku, W.H.-M., Kahn, S.M., Pisarski, R., and Long, K.S. 1984, "Einstein Observations of the Cygnus Loop," *Ap. J.*, **278**, 615.
- Pisarski, R., Helfand, D.J., and Kahn, S.M. 1984, "An X-ray Study of the Remnant of SN 185AD," *Ap. J.*, **277**, 210.
- Reynolds, S.P., and Chanan, G.A. 1984, "On the X-ray Emission from Crab-like Supernova Remnants," *Ap. J.*, **281**, 673.
- Schlosman, I., Shaham, J., and Shaviv, G. 1984, "On the Origin of the Power Law X-ray Spectra of Active Galactic Nuclei," *Ap. J.*, **287**, 534.
- Seward, F.D., Harnden, F.R., and Helfand, D.J., 1984, "Discovery of a 50 Millisecond Pulsar in the Large Magellanic Cloud," *Ap. J. (Letters)*, **287**, L19.
- Worrall, D. *et al.* 1984, "Two Multifrequency Observations of 3C 371," *Ap. J.*, **278**, 521.

## Conference Proceedings 1984 – 1990

- Helfand, D.J. 1990, "On the Origin of the Diffuse X-ray Background," in *Proceedings of the US – USSR Workshop on High Energy Astrophysics*, National Academy Press, in press.
- Helfand, D.J. 1990, "An X-ray Image of the Large Magellanic Cloud: Detection of the Hot Interstellar Medium," in *IAU Symposium No. 148, The Magellanic Clouds and their Dynamical Interaction with the Milky Way*, eds. R. Haynes (Dordrecht: Kluwer).
- Wang, Q., and Helfand, D.J. 1990, "An X-ray Survey of OB Associations in the Large Magellanic Cloud," in *IAU Symposium No. 148, The Magellanic Clouds and their Dynamical Interaction with the Milky Way*, eds. R. Haynes (Dordrecht: Kluwer).
- Halpern, J. 1990, "Black Holes in the Balance," *Nature (News and Views)*, **344**, 713.
- Halpern, J. 1989, "X-ray and Optical Observations of Geminga," in *Proceedings of the Gamma-Ray Observatory Science Workshop*, Goddard Space Flight Center, p. 4-166.
- Helfand, D.J., and Becker, R.H. 1987, "The Progenitors and Products of Supernovae," in *NATO Advanced Study Institute on High Energy Phenomena around Collapsed Stars* (Cargese, Corsica 2-13 September 1985) ed. F. Pacini (Dordrecht; Boston: D. Reidel; Hingham, MA: Distributed in the U.S.A. and Canada by Kluwer Academic Publishers).
- Helfand, D.J., and Wang, S.G. (co-editors) 1987, "The Origin and Evolution of Neutron Stars," (Dordrecht, Reidel).
- Helfand, D.J. 1985, "The Creation of Compact Objects in the Local Group," in *Seminar on Galactic and Extragalactic X-ray Sources*, (Tokyo, Japan, 16-18 January 1985), eds. Y. Tanaka and W.H.S. Levin (Tokyo: Institute of Space and Astronomical Science).
- Chanan, G.A., Helfand, D.J., and Reynolds, S. 1984, "An Optical Synchrotron Nebula Around the X-ray Pulsar 0540-693 in the LMC," in *Birth and Evolution of Neutron Stars: Issues Raised by Millisecond Pulsars* ed. S.P. Reynolds and D.R. Stinebring (NRAO: Greenbank), p. 40.
- Helfand, D.J. 1984, "X-ray Synchrotron Nebulae and the Origin of Neutron Stars," in *COSPAR/IAU Symposium on Advances in High Energy Astrophysics and Cosmology, Adv. Space Res.*, **3**, 29.

- Helfand, D.J. 1984, "X-ray Surveys of the Magellanic Clouds," in *IAU Symposium No. 108, The Structure and Evolution of the Magellanic Clouds*, eds. K. de Boer and S. van den Bergh (Dordrecht: Reidel), pp. 293-304.
- Helfand, D.J. and Becker, R.H. 1984, "Radio Observation of New and Used Crab-like Supernova Remnants" in *The Crab Nebula and Related Supernova Remnants*, Proceedings of a Workshop held at George Mason University, Fairfax Virginia, October 11-12, 1984, eds. M.C. Kafatos, and R.B.C. Henry (Cambridge: Cambridge University Press), p. 241-245.
- Ku, W.H.-M, Long, K.S., Pisarski, R., and Vartanian, M. 1984, "Detailed X-ray Observations of the Cygnus Loop," in *Proceedings of the SPIE Conference on Instrumentation in Astronomy V*, published in *SPIE*, Vol 445, pp. 384-393 (Society of Photo-Optical Instrumentation Engineers, Washington 1984).
- Long, K.S. 1984, "The X-ray Properties of Normal Galaxies," in *Proceedings of XXIV COSPAR*, published in *Adv. Sp. Research*, 2, 1984, pp. 177-188.
- Shaham, J., 1984, "Isolated and Binary Millisecond Pulsars and Accretion Spun-up Neutron Stars," in *Birth and Evolution of Neutron Stars: Issues Raised by Millisecond Pulsars* ed. S.P. Reynolds and D.R. Stinebring (NRAO: Greenbank), p. 107.

